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Standardizing the evaluation of brown tree snake trap designs

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Abstract

The introduced brown tree snake has had devastating impacts on the native vertebrate fauna of Guam. Trapping is the primary means by which brown tree snakes are removed, either in support of reintroduction of endangered species or to deter their movement from Guam in cargo. Traps used to control brown tree snake populations have been continually evolving since the 1980s. Before general operational implementation of a new design, the efficacy of new trap developments must be demonstrated. In this paper we combine the current knowledge about brown tree snake control objectives and practicalities, the information gained from a variety of brown tree snake trapping studies over the years, and fundamental statistical principles and methods to standardize procedures for testing developments in brown tree snake traps.

Introduction

The brown tree snake (*Boiga irregularis*) on Guam is a severe example of the negative effects that an introduced predator can have on native insular fauna (Savidge 1987). This nocturnal snake, brought accidentally to Guam in post World War II cargo shipments, has attained extraordinary population densities throughout the island (Rodda *et al.* 1992a). As a result of snake predation, only 3 of 12 native species of forest birds survive in the wild, with one of those on the verge of elimination (National Research Council 1997). The Guam population of Marianas fruit bat (*Pteropus mariannus*), already impacted by hunting, has been further decimated by snake predation (Wiles *et al.* 1995). Many of Guam's native species of lizards also have been negatively impacted by brown tree snake populations (Rodda & Fritts 1992).

Guam also has suffered economic and social consequences of the brown tree snake introduction. Brown tree snakes prey on poultry and other small domesticated animals (Fritts & McCoid 1991). They climb utility poles and wires, causing frequent power failures that result in millions of dollars of damaged equipment, lost productivity, and repair costs (Fritts *et al.* 1987). Furthermore, the brown tree snake is mildly venomous and readily enters buildings where it may present a health threat to small children (Fritts *et al.* 1990).

Brown tree snakes are well suited for transport to, and establishment at, other locations. They are agile climbers that seek refuge from heat and light during daytime. Cargo, shipping containers, and transport vessels may offer ready daytime refugia. The snakes are opportunistic feeders that consume a highly varied diet and may survive extended periods without food (Greene 1989; Linnell *et al.* 1997; Rodda *et al.* 1999c; Savidge 1988; Shine 1991; Shivik & Clark 1999). These elements, coupled with Guam's position as a focal point for commercial and military shipments of cargo and passengers throughout the western Pacific, present a significant threat for further dispersal of brown tree snakes from Guam. Brown tree snake sightings have been documented on many Pacific islands, with an incipient population speculated to exist on Saipan in the Commonwealth of the Northern Mariana Islands (McCoid *et al.* 1994).

A federal program has been in place on Guam since late-1993 to deter the dispersal of brown tree snakes through cargo to vulnerable destinations (Engeman *et al.* 1998b; Vice *et al.* 1999). Trapping has been demonstrated to be highly effective at removing brown tree snakes in a number of studies (e.g., Engeman *et al.* 1998a; Engeman & Linnell 1998). Since the inception of that program, trapping brown tree snakes has been the primary means by which low snake-population buffer zones have been produced in the vicinities of air- and sea-ports, and other cargo staging areas. Much of the current brown tree snake control work now also focuses on the use of trapping as the primary means for removing brown tree snakes from sites on Guam being prepared for endangered species reintroduction and/or protection (Anderson *et al.* 1998).

Brown tree snake trap development

The history of brown tree snake trapping has shown considerable evolution in trap design. Funnel trap designs for snake control purposes were first applied for bullsnakes (*Pituophis melanoleucas*) predating waterfowl nests at a Nebraska wildlife refuge (Imler 1945). The standard brown tree snake design has also followed a basic funnel design, with the early versions used in brown tree snake research handmade of metal window screen with pliable plastic window screen to form the funnel entrances (Rodda *et al.* 1992b). By the early 1990s, a commercially available minnow trap made of galvanized 6 mm wire mesh was modified for snake capture by adding one-way doors, and used in brown tree snake research (Rodda *et al.* 1999b describe the development of this trap up through about 1992). At that time, a mouse protected in an interior wire cage was used as the attractant to lure brown tree snakes into the trap. By the end of 1993, large-scale operational control was implemented on Guam around ports and other cargo staging areas. A two-piece, commercially available crayfish trap was converted into a snake trap by adding one-way doors to each end and inserting an internal cage to house and protect the live mouse used as an attractant (Linnell *et al.* 1998). Since then, a variety of one-way doors have been developed and tested for the traps. An immovable hinge pin that allows the door to swing shut, even when the trap is rotated on its horizontal axis by 75–80°, was a key development (Linnell *et al.* 1998). A custom-designed one-piece trap incorporating the positive elements of the two-piece crayfish trap, but creating a protective chamber for the mouse that was externally accessible, was developed and is the current trap used for widespread control. This design allowed for much more efficient care of the mouse in the field while maintaining high capture efficacy. Currently, a door flap offering maximum visibility of the mouse in the trap appears to be most effective for drawing the snake inside (Vice unpublished data). It is constructed of one-quarter inch wire mesh attached with the immovable hinge pin. A subsequent model of one-piece trap designed to resist the damage inflicted by nontarget animals, such as coconut crabs (*Birgus latro*) and rats (*Rattus* spp.), had the trap exterior constructed with drilled PVC pipe instead of wire mesh. This trap was recently found to outperform the standard trap, probably because the attractant mouse was only readily visible to a snake when it was at the entrance, whereas wire mesh trap bodies allowed visibility without directing the snake to an entrance (Vice & Engeman, unpublished data).

Before widespread implementation of new trap designs or trap components to control brown tree snakes, tests to assess their capture efficacy are needed to insure maximal efficacy of the control program. Here, we combine the information available on brown tree snake trapping techniques and results, the criteria and objectives for evaluating brown tree snake traps, and fundamental statistical design principles to set out a standard protocol that can be used as a basis for trap evaluations.

Trapping methodology for controlling brown tree snakes

Trapping locations on Guam

Trapping is applied as a control tool primarily around air- and sea-ports, other cargo staging areas, and also in some restricted-access military properties. Trapping is also applied on some federal and territorial government properties to reduce brown tree snake predation on endangered species or to prepare the site for endangered species reintroduction to the wild. In each situation the forest habitat is fragmented by human development, such as roads, buildings, lawns, and other cleared areas. Considerable research has been conducted to examine the efficacy of trapping and optimal trap placement strategies in an operational context (Engeman & Linnell 1998, in press; Engeman *et al.* 2000, 1998a–c; Rodda *et al.* 1992b, 1999a).

Trap placement

Traps typically are hung at chest height in trees on the forest perimeter, spaced at approximately 20 m. Forest perimeter trap placement is a far more efficient and environmentally acceptable placement strategy for maintaining the traps and caring for the live mice than cutting trails for forest interior placement. Besides being the most efficient use of labor resources, this placement strategy has been demonstrated in a variety of trapping studies to be the most effective for capturing brown tree snakes (Engeman & Linnell 1998; Engeman *et al.* 1998a–c), including forested plots up to 18 ha (Engeman *et al.* 2000). The 20 m trap spacing has been highly effective for control programs, although evidence exists to suggest that a wider spacing may not reduce captures in some situations (Engeman & Linnell in press). In some areas, especially more developed areas where forest habitat is minimal or missing, traps are placed on fences to take advantage of the brown tree snake's propensity to use these structures for foraging or travel (Engeman *et al.* 1999; Rodda 1991). Traps hung on fences have been shown to have similar capture rates to traps hung in a parallel forest edge (Engeman & Vice in press). Traps in control programs are checked weekly for snake captures, because this is the frequency with which the mice used as attractants require maintenance in the field. Mouse maintenance, even though streamlined with improvements in trap design and feeding methods, still constitutes a large portion of the field labor in a trapping program.

Snake removal rates

Weekly capture rates of brown tree snakes from a variety of sites on Guam in a control program context have followed an exponential decay (Engeman & Linnell 1998, in press; Engeman *et al.* 2000; Rodda *et al.* 1999a), with the following equation derived to describe the general rate of removal (Engeman unpublished data):

$$y_i = ae^{-bx_i},$$

where y_i represents the capture rate as brown tree snake per trap-night (bts/tn) for the ith week, x_i is the ith week, and the parameterization for the general model is $a = 0.178$ and $b = 0.499$. Based on the general equation, an average of 42% of snakes that would be removed from a plot in a two-month period would be removed in the first week of trapping, and 67% would be removed in the first two weeks. Understanding the patterns of removal allows managers to plan the use of trapping resources and provides useful information for optimally designing tests of new trap designs.

Criteria (variables) for evaluating trap designs

Before defining the variables that form the bases for comparing trap designs, we define what we mean by trap designs. Design developments that merit evaluation before adoption as a standard feature in a control program could include new designs for the general configuration of the trap, the use of new construction materials in the trap or its components, new door designs, new housing methods for the live mice used as attractants, and alternative attractants than the live mice.

Trap efficacy

In general, the variable of far greatest interest for evaluating trap designs is the trap efficacy, which is most appropriately measured by capture rate of brown tree snakes. This variable is measured on each experimental unit (discussed later) as the number of brown tree snakes captured per trap-night. That is, the average number of snakes captured each night by each trap of a particular design for each experimental unit. While there are a number of ancillary variables of interest, this is the variable that relates most directly to the purpose of brown tree snake control, the removal of brown tree snakes, and therefore is the primary variable for evaluating trap designs.

Escape rate

Although capture rate is the primary variable of interest, escape rate may also be examined. Typically, escapes from snake traps have been assessed by placing crush tubes of lightweight aluminum foil in the traps to detect if a snake entered, but was not captured (e.g., Linnell *et al.* 1998; Rodda *et al.* 1999b). With recent models of traps, escape rates have been low (e.g., Linnell *et al.* 1998). Thus, unless trap designs display escape rates differing by orders of magnitude, or an extraordinary number of trap lines are used, the chance of detecting a difference is low. On the other hand, when dealing with only very small escape rates, such differences likely would be of little practical value.

The primary objective in monitoring escape rates in new designs would be to verify that it does not permit a gross increase in escapes, although this also would manifest itself as a lower capture rate.

Snake size

An analysis of the size of snakes captured by each trap type provides useful information for evaluating traps. Some reports in the literature have indicated that the average size of snakes captured by hand while spotlighting differed from that for snakes captured in earlier models of traps (Rodda *et al.* 1999b), while a recent study found no differences in average size, or distribution of sizes, of snakes captured by trapping versus those captured by hand during spotlighting (Engeman & Vice in press). The utility of examining size is to insure that a new design does not exclude segments of the brown tree snake population already being captured by the traps in place, or to see if it picks up new segments of the population. Size is usually measured as the snout-vent length (SVL). Total length is less accurate, as portions of the tails of these slender snakes are often missing, and weight is probably an even more variable measure of size, as it fluctuates greatly with recency of feeding or length of time spent in a trap.

Labor

New elements of trap design also may be aimed at reducing labor in the field. Effort in the field relates first to the difficulty in accessing the traps, which is minimized because perimeter trapping is also the most effective placement strategy. Secondly, effort also relates to the ease of caring for the live mice used as attractants and the ease with which captured snakes are removed. Traps are inspected weekly. During each trap servicing, any captured snakes are removed, and a new potato as a water source and a new food block are placed in the mouse compartment, and the compartment is cleaned as necessary. The labor involved with new designs is evaluated by measuring maintenance times, both with and without a snake in the trap.

Mouse survival

As long as live mice are the most practical attractant to lure brown tree snakes into traps, mouse survival will be a consideration for evaluating trap designs. Concern for mouse survival is borne not only out of a continual heightening of awareness for animal welfare, but also out of snake control practicalities, whereby greater mouse survival translates into reduced programmatic costs and labor for their production and maintenance. The ideal means for evaluating mouse survival is to monitor individual survival times for the mice used (exclusively) in each trap type being tested. This allows survival analysis techniques to be applied to compare trap designs (e.g., Kalbfleisch & Prentice 1980).

Experimental design considerations for trap comparisons

The inferences from comparing trap designs that are candidates for use in operational control should be directly applicable to operational usage. Therefore, the trapping methods used in trap assessments should simulate those applied in a control program. However, we assume any new design will be in limited supply until it is demonstrated to be at least as effective as a standard model. With limited time and resources, the discriminative information among trap designs being tested must be maximized. Thus, in this section we incorporate three critical elements into developing experimental designs for assessing brown tree snake traps: (1) conducting tests as in an operational control program, (2) producing statistically valid and sensitive experimental designs, and (3) using practical and efficient methods to be carried out with minimal resources and manpower.

Inferences and variability among sites

Different areas on Guam are characterized by different average sizes and size distributions of snakes, different population densities, different prey base structures, different control histories, etc. (e.g., Savidge 1991; Rodda *et al.* 1992a; Vice *et al.* 1999). Each factor could influence capture rates and/or susceptibility to trapping. The variability among potential trap sites implies that a diversity of sites is needed to provide generality of inferences about trap designs.

When there is a high degree of variability among experimental units (sites for traplines in our case), repeated measures or randomized block designs are the standard means by which comparative capabilities are maximized (e.g., Winer 1971). These designs provide direct comparisons among treatments (trap designs) and allow some control over the heterogeneity among experimental units. Testing trap designs should provide head-to-head trap comparisons while maximizing the discriminatory information (sample size) within available resources. The head-to-head comparisons are accomplished by using each design to be tested in each trapline, including the current standard design used for control as a basis for comparison. The traps should be applied in a random order, with the order repeated within a trapline. Thus, the trapline is the experimental unit and generality of inferences is obtained by applying traplines at multiple sites. The number of trapline placements determines the sample size and the sensitivity for discriminating among trap types. The data structure and analysis would follow that of a repeated measures design where the trapline is treated as a subject receiving multiple observations (observations for each trap type).

Maximizing sample size

Because each site to which a trapline is applied has each trap type in equal proportion, the local snake population is equally subjected to each trap design. Snake population density and other site characteristics are accounted for by the analytical design applied to repeated measures data. This places the design emphasis on maximizing the number of trapline placements within the constraints of experimental materials and manpower. Because such a high proportion of the snakes likely to be caught are removed in the first week or two of trapping, this is the time frame when there is the greatest potential to show differences in capture rates. This is fortuitous, because the most practical way to generate multiple trapline placements with limited resources is to move a trapline after the first or second trap check.

Trap placement

Trap placement on perimeter of the forest is the primary placement used for operational control, and it has been demonstrated to be the most efficient and effective placement strategy (Engeman *et al.* 2000,1998c; Engeman & Linnell 1998). Therefore, perimeter trapping is the most appropriate for use in trap testing. Other placements could result in lower capture rates (Engeman & Linnell 1998) with reduced discriminatory capabilities among trap designs. Also, they would not reflect how traps would be used in practice as a control tool. An area of fenceline parallel to forest edge also might be considered for trap placement, particularly if control has not previously suppressed populations.

Trap servicing effort

When changes in trap design are developed that could alter trap maintenance, their effects on maintenance times should be examined. Because there is a great deal of variability among the physical capabilities and skills of the trappers, the same design principles apply for assessing maintenance times as for assessing capture rates. That is, inferences should be broadly applicable to the people conducting control trapping. Thus, a variety of trappers should be timed using each trap type, both with and without a snake in the trap.

Data structure and analyses

The capture rate, escape rate, and the snake size data produce the mixed linear model data structure (e.g., Littell *et al.* 1996; McLean *et al.* 1991; Wolfinger *et al.* 1991) characteristic of repeated measures or randomized blocks experiments (e.g., Winer 1971), where the traplines are the units (subjects). Trap maintenance times also follow a mixed linear model data structure, but the experimental units are the trappers that are timed while maintaining the mice in each design, with and without snakes in the trap. Examination of the interaction means for trap design and snake presence can provide useful information on where design improvements have increased efficiency, and where more can be developed. Mixed linear model data are appropriately analyzed using software such as SAS PROC MIXED (SAS Institute 1992, 1996, 1997).

Mouse survival

Ideally, mouse survival among trap designs could be examined using the nonparametric product-limit survival analysis (Kaplan & Meier 1958). Similarly, new products are under development for enhancing the care of mice, such as more efficient means of water delivery (L. Clark, personal communication), and mouse survival could also be used to examine such developments, too. The presence of differences in survival, as well as in the shapes of the survival curves each could provide useful information for management of mouse resources and for identification of where improvements can be made in trap design. However, mouse survival for recent designs has been very high (Vice unpublished data). Hence, there is a good likelihood that there will be insufficient mortality to apply these methods and distinguish among designs. In that case, mouse survival might be analyzed using contingency table methods, especially those applicable for small cell sizes (D'Agostino *et al.* 1988; McDonald *et al.* 1977).

Discussion

The preceding information has given efficient, sound experimental designs for assessing brown tree snake traps in a practical context. The ingredients for carrying out trap comparisons in this manner are summarized in Table 1. The objectives, methods, and inferences are directly reflective of control procedures. As registration of toxic baits for brown tree snake control looms closer on the horizon (Savarie *et al.* 2000, in press), the same experimental design concepts and considerations can be directly applied to evaluation of different bait station designs. This also holds true for other toxicant delivery devices, such as for dermal toxicants should they reach the field testing stage (Brooks *et al.* 1998; Savarie *et al.* 2000).

Table 1. Summary outline of considerations for designing tests to evaluate brown tree snake traps

- I. Simulate trapping as applied for operational control
  - A. Trap lines on forest perimeters
  - B. Traps spaced at 20 m
  - C. Weekly trap checks
  - D. Snakes removed from environment
- II. Multiple trap line placements form experimental units
  - A. Randomize order of traps (repeat order within trap lines)
  - B. Move trap line after 1–2 weeks (maximizes discriminatory information , sample size, and breadth of inferences)
- III. Measurements
  - A. Essential
    - 1. Capture rate for each trap type on each trap line
  - B. Important, but optional
    - 1. Size (SVL) of snakes
    - 2. Escape rates
    - 3. Mouse survival times
    - 4. Trap/mouse maintenance times
      - a. Without a snake in the trap
      - b. With a snake in the trap
- IV. Analyses
  - A. Mixed linear model
    - 1. Capture rates
    - 2. Average size
    - 3. Trap maintenance times
    - 4. Escape rates (assuming enough escapes detected)
  - B. Categorical data analyses (including small cell contingency tables)
    - 1. Snake size distribution
    - 2. Snake escape proportion
    - 3. Mouse survival proportion
  - C. Survival analyses
    - 1. Mouse survival

We emphasize here that, while having some commonalities, the objectives for comparing brown tree snake trap designs are not the same as the ongoing efforts for assessing furbearer traps. The interest in furbearer trap assessments lies not so much in direct comparisons of traps, but rather in the establishment of minimal standards which traps must meet, and as such, efficacy and efficiency of traps are joined by selectivity, animal injury levels, and operator safety as assessment criteria (Canac-Marquis 1998; Engeman *et al.* 1997; Hamilton *et al.* 1998; International Organization for Standardization 1999; Trusso & Hamilton 1998).

We recognize that trap comparisons also may be a byproduct of other general biological brown tree snake experiments, in which case other designs and methods may be applied to meet the primary objectives. In such cases, we caution that an inability to statistically detect (even large) differences among traps does not mean they do not exist. An efficient design specifically aimed at detecting differences is the optimal course for distinguishing among trap designs.

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